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Photovoltaic electricity scenario analysis in urban contests: An Italian case study

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ABSTRACT

This paper shows a methodology for the assessment of the photovoltaic potential in urban areas using Google Earth™ tool that provides either satellite images of the roofs of buildings or their number of floors by means of the Street View function. The applicability of the methodology has been tested on a selected urban area of the city of Palermo in the South of Italy. After classifying roofs according to the shape, orientation and pitch of buildings with different morphologies, the share of energy generated by the installable PV systems was evaluated with regard to the number of floors. Moreover the coverage of the electricity demand was investigated on the basis of the consumption of electricity of the households. The results of the energy assessment have been screened considering the economic feasibility of grid-connected photovoltaic systems. The proposed methodology permits to select a threshold number of floors of the buildings in correspondence of which the PV system that may be installed, and the consequent production of electricity, may not recover the costs for installation and maintenance of the system. This aspect has also been analyzed by considering the main factors that influence the computation, such as the mismatch between generated and consumed electricity and the shading effects due to the surrounding obstacles. The methodology could also be used to assess the effectiveness of the national incentives to support the diffusion of the PV systems in the short term.

Contents

1. Introduction

The European Union (EU) has defined many climate and energy targets to be meet by 2020, known as the "20-20-20" targets. With the Directive 2009/28/EC, the EU stated the national overall target for the share of energy from renewable sources for each Member State. The share of energy from renewable sources in gross final consumption of energy in 2020 would be at least 17% of the total for the Italian case. To achieve the ambitious latter target the solar energy could play the main role in urban contests.

To reach the above target the economical aspect is becoming an issue. It means that the PV systems have to be a feasible economic investment, taking into account that the expected price of PV technologies decreases and the expected price of energy

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Nomenclature

$C_{j,t}$	generic *j*th cost at the generic *t*th year [€]
C_{PV}	energy cover factor [%]
C_t^*	cash flow at the generic *t*th year [€]
C_t	annualized cash flow at the generic *t*th year [€]
C_0	initial investment cost [€]
D_{Total}	electrical energy demand [kWh]
D_{day}	day energy demand [kWh]
D_{night}	night energy demand [kWh]
E_{cons}	electricity consumed [kWh]
E_{PV}	electricity produced by the PV system [kWh]
i	weighted average cost of capital [%]
I	current generated by the panel [A]
I_L	photocurrent [A]
IRR	internal rate of return [%]
I_0	reverse saturation current [A]
n	diode quality factor
N	lifetime of the investment [years]
NPV	net present value [€]
$P_{j,t}$	generic *j*th profit at the generic *t*th year [€]
R_s	series resistance [Ω]
R_{sh}	shunt resistance [Ω]
T	temperature of the panel [K]
V	voltage generated by the panel [V]

increases in the future; consequently it is more likely that PV systems will become more affordable. It is basic to consider the size of the studied system. Actually, when the assessment refers to a specific PV system installed on a single-family house, even considering many aspects of the problem (panels, inverters, orientation, pitch, obstructions, economic analysis, etc.) the results of the predictions cannot be used to define scenarios for a whole city or region [1–3]. On the other hand, when the purpose of the study is to analyse the energy potential of a country, or even a continent, it is extremely difficult to take into account all parameters of the problem [4–7].

The potential of solar electricity generation was assessed for areas whose surfaces varied from a flat [8,9,10] to a whole city [11] or a continent [12]. To evaluate the roof collecting surfaces, Vardimon [13] considered that 18–24% of the area was available for slanted roof, while flat roofs had an availability ratio of 50–70%. Ordóñez et al. [14] estimated availability ratios of 79–98% for pitched roofs and of 65–80% for flat roofs, depending on the typology.

Many researchers have investigated the effectiveness of supporting measures for the production of electricity by PV systems. Papadopoulos et al. [15] showed a quantitative assessment of the feed-in tariff (FIT) introduced in Greece. Campoccia et al. [16] compared the supporting measures adopted by France, Germany, Italy and Spain. Dusonchet et al. [17,18] extended the comparison to 17 western and 10 eastern European Union countries. Due to the many differences in granted subsidies and prices of energy it is quite impossible to select the most effective option for the examined case studies.

To use electricity where it is produced it is very gainful for both the self-producing consumer, whose energy bills will lower, and the electrical manufacturers that will reduce the production costs for transmission and distribution of electricity. The rapid decrease in the photovoltaic (PV) module cost, the escalation in the prices of petrochemical fuels and the national supporting measures have encouraged the diffusion of PV systems that, in the past, were considered attractive only for special applications in remote isolated areas. Nowadays PV systems are simple and easy to set up and for this reason many building owners have become interested in them, as they believe they could advantageously exploit the abundant, free, clean and inexhaustible solar energy collected by their roofs, even in the city contest. Unfortunately, the payback period for PV systems is still quite long.

To evaluate the potential impact of the PV systems on the production of electrical energy in the urban contests, a simple methodology for assessing the energy and economic performances of the above technology was defined. The methodology is applied to a district of Palermo, a city of one million of inhabitants of the South of Italy, to test the effectiveness of the method on a real case study.

2. Methodology

To produce the same amount of electricity consumed by the inhabitants is an ambitious goal for PV systems. An effective way to face the problem is assessing the amount of electricity demand covered by the PV system. Even though it is important to point up the energy cover factor of a PV system, which is the ratio of the electricity produced and the electrical energy demand, it may happen that the PV system gives little economic advantages during the operative phase. The joined analysis of energy and economic aspects is of basic importance for evaluating the real outcomes of investments. To evaluate these outcomes the proposed methodology goes through the following steps.

Energy assessment:

- identification of buildings of the district;
- estimation of number of floors and flats of each building;
- identification of slanted tiled roofs and flat roofs;
- shape classification of roofs;
- identification of roof surfaces available for PV systems;
- evaluation of the roof surface available for each flat;
- design of the PV system for each flat;
- estimation of solar energy collected by the PV system during its lifetime;
- estimation of the electricity produced by the PV system during its lifetime;
- estimation of the electricity consumed by the owner of each flat during day and night.

Economic assessment:

- evaluation of costs of PV system devices during its lifetime;
- evaluation of costs for maintenance, servicing and insurance against damage during PV system lifetime;
- estimate of value of electricity produced by the PV system during its lifetime;
- estimate of cost of electricity consumed by the owner of the flat during PV system lifetime;
- estimate of value of sold electricity produced by the PV system during lifetime;
- estimate of value of incentives during PV system lifetime;
- estimate of values of significant financial parameters (inflation rate, weighted average cost of capital, change in the prices of electricity and PV devices, etc.);
- evaluation of financial analysis indicators (net present value, internal rate of return, pay-back period, etc);
- assessment of the feasibility of the PV system;
- exclusion of the roofs that are economically unsuitable;
- evaluation of all economically suitable roofs of the district;
- sensitivity analysis applied to most significant physical and economic parameters.

The methodology is able to evaluate the economic profit of each homeowner referring to the portion of roof available for the installation of a PV system. Furthermore the realistic PV electricity percentage of the energy required to reach the "20-20-20" target in the city district can be estimated.

2.1. Classification of roofs

The assessment of the PV potential requires a detailed analysis of the shape of buildings and the evaluation of net roof surfaces that are available for the installation of the PV modules. Moreover it is important to identify the portion of the shared roof available for each co-owner that in turn depends on the number of floors of the building.

A very effective way to face the problem is surveying the buildings of the district by means of Google Earth™ and using the Street View function to determine the number of floors of each building of the district.

The shape classification of roofs requires different approaches for slanted and flat roofs. While on a flat roof the orientation and pitch of the PV panels can be chosen independent from the orientation of the building to achieve the highest energy production, the PV panels located on slanted roofs are usually installed with the same orientation and pitch of the roof. The PV panels installed on slanted roofs rarely have the optimal values of orientation and pitch; moreover the presence of triangular surfaces, typical of slanted hip roofs, reduces the area of roof exploitable for the installation of PV modules. For the above reasons, the classification of slanted roofs should be based on a detailed criterion able to point out the differences between the various kinds of slanted roofs.

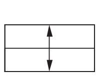
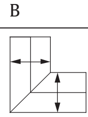
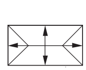
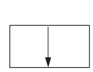
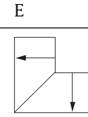
To classify slanted roofs an analysis of the disposition of the urban context has to be developed. The roof of many buildings looks like a complex composition of different elementary roof shapes such as gable, hip and skillion. Some buildings have roofs orthogonally joined; besides, the roofs have different orientations.

For a generic district characterized by a regular square layout of streets and a well ordered orientation of buildings, the 5 types of elementary shapes shown in Table 1 have been identified (arrows in the drawings indicate the slope direction).

Types A and B are gable roofs, type C is a hip roof and types D and E are skillion roofs. The elementary roof types of Table 1 should be rotated to consider all the different orientations of buildings. Depending on the local building traditions, some other kinds of roof shapes may be obviously considered.

A less complex criterion can be used to classify flat roofs because in this case the shape of the roof and the orientation of the building marginally affect the design and the energy efficiency of the PV system. Flat roofs can be sorted by the size and clustered in an adequate number of classes. Once evaluated the area mean value of each class, a number of buildings of the district can be selected to represent each class. Each selected building should be regularly shaped and have a roof area close to the area mean value of the flat roof class that it represents. According to the above criteria, each building is catalogued assigning the corresponding roof type, the roof surface area, the number of floors and the total surface area of flats located in the building.

Table 1
Elementary slanted roof shapes.

A	B	C	D	E
				

2.2. Electricity produced and consumed

To correctly design a PV system it is necessary to define the PV field, whose size is related to the available roof surface. For a multi-storey building the portion of the shared roof available for each co-owner depends on the ratio of the area of each flat to the total area of the flats located in the building. When the information about the dimensions of flats is unavailable, it may be assumed that all flats have the same gross area; the portion of roof available for each co-owner can be evaluated by simply dividing the roof surface covering the topmost flats by the number of the superimposed flats of the building.

Because the global efficiency of a PV system continuously changes during the time, to assume a constant value for the PV system efficiency may obviously lead to an inaccurate estimate of the energy production. To estimate the electricity production some accurate software for designing PV systems should be used. In this paper the PVsyst 5.06 [19] software has been employed. PVsyst includes monthly data of the global irradiation, temperatures and wind for numerous locations. All PV devices (panels, grid inverters, batteries, regulators, etc.) are described by using electrical equivalent models based on the performance data issued by manufacturers. To describe the operating of a PV module, PVsyst uses the one diode model, which is a simplified version of the model proposed by Wolf et al. [20] and studied by many other researchers [21–25]. The model is based on the current–voltage five parameters implicit Eq. (1):

$$I = I_L - I_0(e^{(V+IR_s)/nT} - 1) - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where following the traditional theory, the photocurrent I_L depends on the solar irradiance, the reverse saturation current I_0 is affected by the PV cell temperature and n, R_s and R_{sh} are constant.

Depending on the instantaneous power, the efficiency of the inverter is generally characterized by a power transfer function during the operational phase. The efficiency curve is rarely explicitly given by the manufacturers. PVsyst describes the electrical behaviour of inverters by means of an efficiency versus input power characteristic derived from the performance data issued by manufactures.

For the most accurate calculation of the electricity produced by the PV systems, each PV field should be accurately sized on the basis of the real dimension and shape of the portion of roof available for the generic co-owner of each building. To avoid this painstaking procedure, which should be repeated for all the co-owners of the district's buildings, a different approach based on the above classification of roofs is suggested.

Assuming that all flats of the district have the same standard area, the above electricity calculation must be only repeated for each type of roof and each number of floors. The result of each electricity calculation can be divided by the area of the standard flat in order to evaluate the specific value of electricity production for square meter to be accredited to any flat located in a building with any number of floors and type of roof. The electricity produced by each building can be evaluated by multiplying the specific value of the electricity production, which is related to the number of flat and the type of roof, by the global area of the flats of the building. Eventually, the electricity produced by the entire district can be calculated by summing the electrical energy produced by all buildings of the district.

To establish the level of integration of PV systems the produced electricity and the energy demands can be coupled by means of the energy cover factor C_{PV} [26]:

$$C_{PV} = \frac{E_{PV}}{D_{Total}} \cdot 100[\%] \quad (2)$$

in which E_{PV} represents the electricity produced by the PV systems and D_{Total} is the electrical energy demand. D_{Total} can be derived by the information officially issued for the district by the major local electricity transmission grid operators.

Energy cover factor C_{PV} of the district is affected by the energy mismatch that happens when the electricity generation and consumption are not simultaneous. The following cases can lower C_{PV} below 100%:

1) the PV systems are undersized to cover the energy demands D_{Total} and consequently E_{PV} is less than the demand;
2) the PV systems are not undersized, but the generation does not fully covers D_{Total} for a lack of simultaneity.

The study of the second situation would require a dynamic analysis based on the different distribution of the electricity demands during each day because the behaviour of the occupants in using appliances represents a significant aspect of the problem. Anyway, whatever the household habits in using appliances are, the electricity consumed after sunset and before dawn will be never compensated by the energy produced by a grid-connected PV system than does not use the storage. To assess the economic convenience, the mismatch due to the night demands D_{night} has to be always considered in this case. To estimate D_{night} it should be considered that some appliances, like lamps, refrigerators, televisions and personal computers, may be working in the standard flat for some hours from dusk to down; the number of hours should also change with the seasons of the year.

The mismatch represents a significant problem for the public grid managers because can be complex to manage transmission lines when a significant surplus of electricity generated by a great number of PV systems is suddenly and unpredictably transferred to the grid due to the momentary favourable weather conditions. The mismatch also represents an economic disadvantage for the self-producers because the purchase price of electricity is generally higher than the selling price.

2.3. Economic analysis

The convenience of producing energy is related to the electricity demands: as greater is the energy demand, so greater should be the convenience of being an energy self-producer. Obviously many other parameters influence the economic convenience, but generally, once the economic convenience is assessed, it would be appropriate to produce the electricity necessary to fully cover the energy demand.

Prior to estimate the costs and benefits of the options described in this section, the price of electricity and the costs for investments, system devices replacement, maintenance and management and insurance have to be evaluated.

To evaluate the gain for the avoided bill cost, the electricity tariffs issued by local Authority for electricity can be used. The electricity bills must be calculated considering the difference between the bills corresponding to the electricity demand D_{Total} and those referred to the difference between D_{Total} and the energy consumed E_{cons} while the PV systems are producing electricity.

To evaluate the gain in selling electricity, which is calculated on the basis of the exported PV generation $E_{PV} - E_{cons}$, the local income tax in selling the exported PV electricity should be also charged. In estimating the benefits also the FIT settled by the local Government must be obviously considered.

Investment costs of PV systems should be assumed from the market prices of components, considering the cost for labour and fitter's profit. The cost of a PV system mainly depends on the size of the PV field, and consequently on the number of floors, which affects the area of the portion of roof available for the generic co-owner of the building. The number of installed PV panels decreases with the number of superimposed flats whereas the length of the power lines, which connect the PV field with the flat, increases with the height of the building. On the contrary, the cost of the switchboards is fair constant for all sizes of PV systems.

The future costs and revenues of the PV technologies must be determined considering:

- the decreasing of the efficiency of the PV panels every year;
- the maintenance and management costs;
- the replacement of PV panels, inverters and batteries;
- the yearly increasing in the price of electricity;
- the assurance costs, varying with the peak-power of the PV systems;
- the effect of inflation, used to time-discount the costs during the time.

All above economic factors are connected to the cash flows C_t^* obtained by adding algebraically all the costs $C_{j,t}$ and all the profits $P_{j_{n,t}}$ related to the generic tth year:

$$C_t^* = \sum_j P_{j,t} - \sum_j C_{j,t} \tag{3}$$

The cash flows are annualized using the expression:

$$C_t = \frac{C_t^*}{(1+i)^t} \tag{4}$$

where i is the weighted average cost of capital (WACC), which is the index that represents the average expected return on the assets of the owner of the system. The effectiveness of installing the PV systems on buildings can be assessed with the evaluation of the net present value (NPV) and the internal rate of return (IRR):

$$\mathrm{NPV} = \sum_{t=1}^{N} \frac{C_t^*}{(1+i)^t} - C_0 \tag{5}$$

$$C_0 - \sum_{t=1}^{N} \frac{C_t}{(1+\mathrm{IRR})^t} = 0 \tag{6}$$

where N is the lifetime of the investment and C_0 is the initial investment cost.

2.4. Energy-economic analysis

In order to evaluate the effective values of C_{PV} of the district, the results obtained from the energy assessment must be coupled with the results of the economic analysis. Actually, if a PV system is installed on the roof of a house it is because the homeowner thinks that it is worth to spend the money for that purpose. This is the reason why the problem has to be faced from the point of view of a household, by considering the electricity demand of the flat and the economical convenience of becoming an energy producer.

The criterion used by the proposed methodology is assuming that only the economically convenient PV electricity is useful to supply the demand of the district. For this reason the energy produced by the PV systems whose economic analysis showed disadvantageous values of NPV or IRR has to be rejected.

Moreover the sensitivity analysis can be harnessed to forecast the evolution of the effectiveness of supporting measures in order to determine the fair value of incentives during the time; actually the value of incentives should vary during the time because all economic parameters will vary too. A wise supporting policy should avoid giving too much money because it would be an economic loss for the country; adversely, giving too less money can discourage the diffusion of PV systems on private roofs.

Fig. 1. The city of Palermo (provided by Google Map).

3. The case study

The described methodology has been applied to a selected area located in the city of Palermo (Sicily, Italy) (Fig. 1) that is characterized by a regular square layout of streets and a well ordered orientation of buildings (117° East of South and 153° West of South) (Fig. 2).

The district area occupied by the buildings, which was calculated by the maps of Google Earth™, measures 109,207 m^2 (Fig. 2), i.e. 40% of the gross district surface.

According to the basic morphological characteristics of the buildings, two types of residential houses can be distinguished in the district:

1) Old buildings, mostly represented by houses built before the Second World War and characterized by a small number of floors, slanted roofs (about 25° above the horizontal) with different shapes (gable, hip, skillion, etc.), and masonry walls, with a 30–60 cm thickness range, distant each other about 4–5 m; the buildings have a standard depth of about 9 m (Fig. 3). Each flat has an entrance hall, a corridor, 5–6 rooms, a kitchen and bathrooms; the estimated gross surface is of about 150–170 m^2.
2) Multi-storey buildings built in the second half of the 20th century using reinforced concrete. Despite the large flat roofs, which are supposed to provide a high annual PV electricity production potential, these buildings have several shortcomings mostly related to the shading effects due to balustrades, elevator housings, HVAC equipment, water tanks, etc.

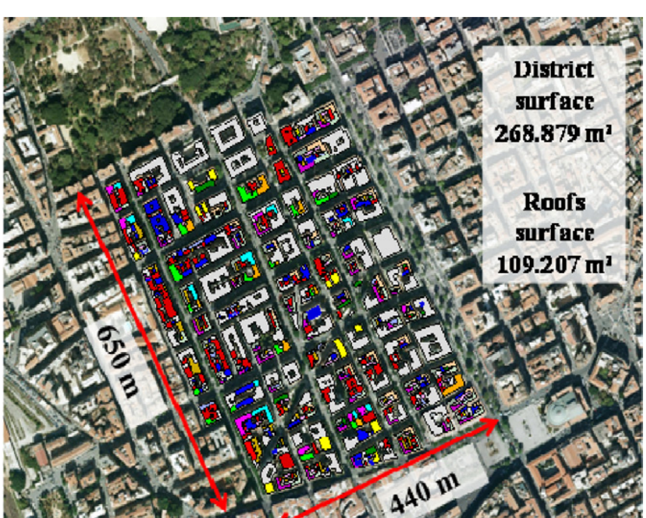


Fig. 2. The analyzed district of the city of Palermo (provided by Google Map).

Fig. 3. Shapes of slanted roofs of the district (provided by Google Map).

Table 2 resumes the areas of the district that may be used to install PV systems.

The results of matching the roof areas with the number of floors are shown in Fig. 4.

Most of the roofs cover buildings of four floors; the majority of the slanted roofs belong to buildings of four floors whereas most of the flat floors cover buildings of eight floors.

3.1. Classification of roofs

To classify the slanted roofs the 16 types of shapes shown in Table 3 have been identified. Types T1–T6 are gable roofs, types T7–T8 are hip roofs and types T9–T16 are skillion roofs. The arrows in the drawings indicate the slope direction. The prevalent roof shapes are the simple gable roofs (T1: 14%; T2: 21%).

The roof of each building was classified according to the above roof types; they were catalogued assigning the corresponding roof type, the surface area and the identification code of the building. The obtained results are summarized in Table 4.

Flat roofs were sorted by the size and clustered in five classes. Once evaluated the area mean value of each class, five buildings, with a roof area close to the class mean values, were selected to represent the five groups of buildings. Table 5 shows the shapes and the surfaces of the chosen five representative buildings; the results are summarized in Table 6.

3.2. Energy generation

The selected technology was a grid-connected PV system with inverters equipped with maximum power point (MPP) trackers. Batteries to store energy were not used. For the design of the PV fields it was used a commercial PV panel (Kyocera KD210GH-2PU)

Table 2
Areas occupied by roofs in the district.

Slanted roofs	60,145 m^2	55.07%
Flat roofs	37,902 m^2	34.71%
Terraces	11,017 m^2	10.09%
Other areas	143 m^2	0.13%

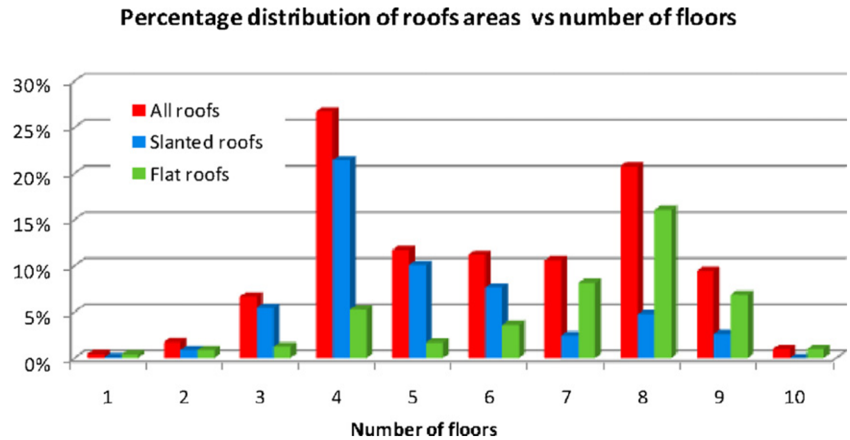


Fig. 4. Distribution of roof areas versus number of floors.

Table 3
Classification of slanted roof shapes.

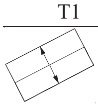
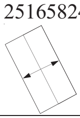
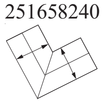
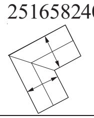
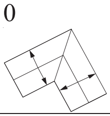
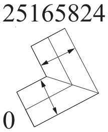
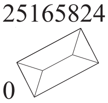
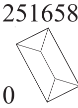
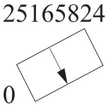
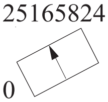
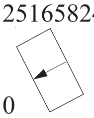
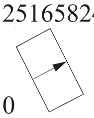
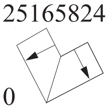
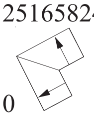
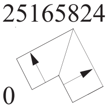
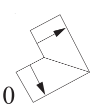
T1	T2	T3	T4
	251658240 	251658240 	251658240 
T5	T6	T7	T8
251658240 	251658240 	251658240 	251658240 
T9	T10	T11	T12
251658240 	251658240 	251658240 	251658240 
T13	T14	T15	T16
251658240 	251658240 	251658240 	0 

Table 4
Surface area of slanted roofs.

Roof type	Surface area [m^2]	Surface area [%]
T1	8162	13.57
T2	12,901	21.45
T3	2690	4.47
T4	2031	3.38
T5	2144	3.56
T6	2219	3.69
T7	1582	2.63
T8	2880	4.79
T9	2296	3.82
T10	1683	2.80
T11	3298	5.48
T12	2906	4.83
T13	3787	6.30
T14	3765	6.26
T15	3618	6.02
T16	4183	6.95
Total	60,145	100.00

whose characteristics are adequately represented by the PVsyst, as it is shown in Figs. 5 and 6.

The PV fields were accurately sized on the basis of the dimensions of the portion of roof available for the generic co-owner of the building; the inverters were selected matching their nominal power with the size of each PV field. For the slanted roofs it was assumed that:

- each flat had a standard surface of 162 m^2 and a fixed dimension (width or length) of 9 m;
- the employed PV panel had the dimensions of 1.50 m $\times$ 0.99 m;
- the PV panels were collocated with the same orientation and pitch (25° above the horizontal) of the roof surface.

According to the above assumptions, the numbers of PV panels installed on the slanted roofs are summarized in Table 7.

The values of the yearly electricity generation were divided by the roof area available for each flat and then multiplied by the total surface of each type of slanted roof in order to calculate the PV generation of all slanted roofs of the district. The obtained results are resumed in Table 8.

For the flat roofs it was further considered that the PV panels were:

- oriented to the South with a pitch of 30°, the yearly most efficient for the city of Palermo;

Table 5
Flat roof representative buildings.

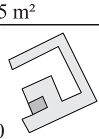
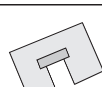
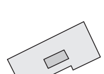
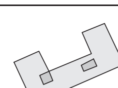
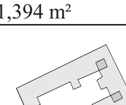
FR1 265 m²	FR2 387 m²	FR3 482 m²	FR4 717 m²	FR5 1,394 m²
251658240 	251658240 	251658240 	251658240 	251658240 

Table 6
Surface area of flat roofs.

Roof type	Surface area [m^2]	Surface area [%]
FR1	3065	8.09
FR2	4267	11.26
FR3	5501	14.51
FR4	9235	24.37
FR5	15,834	41.77
Total	37,902	100.00

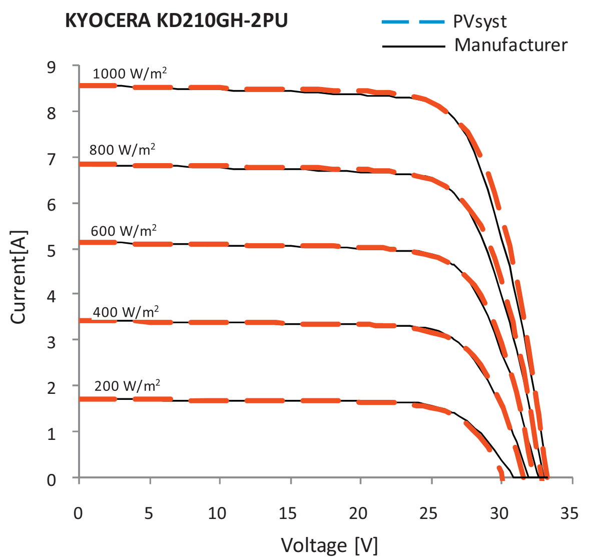


Fig. 5. Comparison between calculated and issued current–voltage characteristics of Kyocera KD210GH-2PU at a silicon temperature of 25 °C.

- shadowed by the present balustrades, elevator housings and other obstructions.

In order to get a significant comparison between the energy generation of flat and slanted roofs, the PV fields sized for the roof area of each selected representative buildings of Table 5 were resized in order to harness the area at disposal of the standard flat (162 m^2). The results of the sizing and resizing procedure are showed in

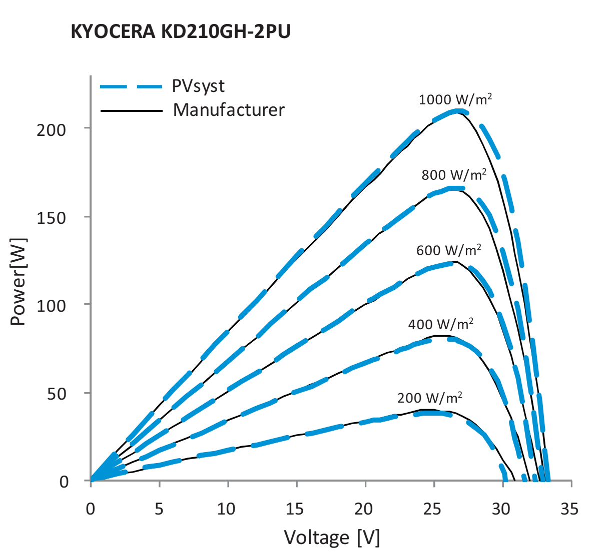


Fig. 6. Comparison between calculated and issued power–voltage characteristics of Kyocera KD210GH-2PU at a silicon temperature of 25 °C.

Table 7
Number of PV panels installed on slanted roofs.

Roof type	Number of floors								
	1	2	3	4	5	6	7	8	9
T1	66	32	20	16	12	8	8	8	4
T2	66	32	20	16	12	8	8	8	4
T3	50	24	14	12	4	4	4	2	0
T4	50	24	14	12	4	4	4	2	0
T5	50	24	14	12	4	4	4	2	0
T6	50	24	14	12	4	4	4	2	0
T7	42	20	12	10	4	4	4	2	0
T8	42	20	12	10	4	4	4	2	0
T9	66	32	20	16	12	8	8	8	4
T10	66	32	20	16	12	8	8	8	4
T11	66	32	20	16	12	8	8	8	4
T12	66	32	20	16	12	8	8	8	4
T13	50	24	14	12	4	4	4	2	0
T14	50	24	14	12	4	4	4	2	0
T15	50	24	14	12	4	4	4	2	0
T16	50	24	14	12	4	4	4	2	0

Table 9. In Table 10 the electricity produced by the flat roofs is listed.

Table 11 lists the percentage values of the availability ratio, i.e. the ratio of the area of the installed PV fields and the area of the portion of the shared roof available for each flat.

The availability ratio does not linearly depend on the number of floors because as smaller the surface of the roof available for the installation is, so greater is the percentage of free space that must be reserved for installation, servicing and maintenance of all devices; additionally the availability ratio decreases for the presence of triangular roof surfaces. Even though the PV fields that can be installed on flat roofs are smaller of those installed on slanted roofs, the optimal potential orientation of the devices installed on flat roofs partially compensates the reduced number of PV panels.

3.3. *Energy household consumptions*

The base case annual electrical energy consumptions of a household were derived by the information officially issued by TERNA [27], which is the major Italian electricity transmission grid operator, and the ISTAT—Italian National Institute of Statistics [28] (Table 12).

According to the above figures, 5.02 persons live in a standard flat of 162 m^2. The yearly average consumption is 5,957.3 kWh per flat.

3.4. *Estimate of the energy cover factor*

Energy cover factor C_{PV} was evaluated according to Eq. (1). To estimate night demands D_{night} it was assumed that the following appliances were working in the standard flat [29–32] from dusk to down:

Table 8
Electricity produced by slanted roofs.

Number of floors	Total roofs area (m^2)	Electricity produced (KWh)
1	64	5,266.96
2	934	41,300.53
3	5923	149,476.55
4	23,316	512,594.78
5	10,947	163,643.40
6	8320	784,56.53
7	2658	224,70.96
8	5158	44,347.64
9	2825	10,223.05
Total	60,145	1,027,780.40

Table 9
Number of PV panels installed on flat roofs.

Roof type	Area [m^2]	Number of floors									
		1	2	3	4	5	6	7	8	9	10
FR1	265	40	20	13	10	8	6	5	5	4	4
FR2	387	83	41	27	20	16	13	11	10	9	8
FR3	484	117	58	39	29	23	19	16	14	13	11
FR4	717	189	94	63	47	37	31	27	23	21	18
FR5	1394	400	200	133	100	80	66	57	50	44	40
Resized PV fields											
FR1	162	24	12	7	6	4	3	3	3	2	2
FR2	162	34	17	11	8	6	5	4	4	3	3
FR3	162	39	19	13	9	7	6	5	4	4	3
FR4	162	42	21	14	10	8	7	6	5	4	4
FR5	162	46	23	15	11	9	7	6	5	5	4

Table 10
Electricity produced by flat roofs.

Number of floors	Total roofs area (m^2)	Electricity produced (KWh)
1	0	0.00
2	0	0.00
3	0	0.00
4	2319	43,090.88
5	320	3014.04
6	3581	45,646.84
7	8011	89,973.85
8	15,911	165,323.55
9	6718	55,099.39
10	1042	7572.44
Total	37,902	409,721.00

- Lamps: 85 W from T_i to 23:00—from 07.00 to T_f
- Refrigerator: 90 W from T_i to 24:00—from 00.00 to T_f
- Television + P.C.: 75 W from T_i to 23:00—from 07.00 to T_f

Because the electricity generated by the PV system is quite small at the beginning and at the end of the day, T_i was assumed 1 h before sunset time and T_f 1 h after dawn time; sunset and dawn time in Palermo on 15th of each month were considered. It was calculated a D_{night} of 716.5 kWh/year and consequently the day energy demand D_{day} = 5240.8 kWh/year. As a consequence 12.03% of the consumed electricity is never supplied by the PV systems and C_{PV} will never surpass 87.93%. Fig. 7 shows the percentage of yearly electricity demand of buildings that can be covered by installing PV systems on roofs of the district.

Table 12
Energy statistic figures for Palermo.

Electricity consumption in Palermo's province	1475.8 GWh/year
Area of inhabited flats in Palermo	22,141,320 m^2
Number of inhabitants in Palermo's province	1,244,680
Number of inhabitants in Palermo	686,711

PV systems supply the 35.8% of the electrical energy required for the district. The energy production is mainly due to the sloped roofs covering buildings of four floors, while the slanted roofs appear the most efficient; in detail, even though the slanted roofs area is less than two times of the flat roofs area, slanted roofs produce 2.5 times the energy of flat roofs.

Fig. 7 shows results that are too optimistic because no shading or other technical problems are considered. Moreover, C_{PV} of the district may be reduced by the energy mismatch that happens when the electricity generation and consumption are not simultaneous during the day.

3.5. Economic analysis

To evaluate the gain for the avoided bill cost, the electricity tariffs issued by the AEEG-Italian Authority for electricity and gas for domestic consumers with an electricity capacity of 3 kW were used.

Table 11
Percentage availability ratios of roofs.

Roof Type	Number of floors									
	1	2	3	4	5	6	7	8	9	10
T1	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T2	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T3	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T4	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T5	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T6	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T7	38.5	36.7	33.0	36.7	18.3	22.0	25.7	14.7	0	–
T8	38.5	36.7	33.0	36.7	18.3	22.0	25.7	14.7	0	–
T9	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T10	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T11	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T12	60.5	58.7	55.0	58.7	55.0	44.0	51.3	58.7	33.0	–
T13	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T14	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T15	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
T16	45.8	44.0	38.5	44.0	18.3	22.0	25.7	14.7	0	–
FR1	14.8	7.4	4.3	3.7	2.5	1.9	1.9	1.9	1.2	1.2
FR2	21.0	10.5	6.8	4.9	3.7	3.1	2.5	2.5	1.9	1.9
FR3	24.1	11.7	8.0	5.6	4.3	3.7	3.1	2.5	2.5	1.9
FR4	25.9	13.0	8.6	6.2	4.9	4.3	3.7	3.1	2.5	2.5
FR5	28.4	14.2	9.3	6.8	5.6	4.3	3.7	3.1	3.1	2.5

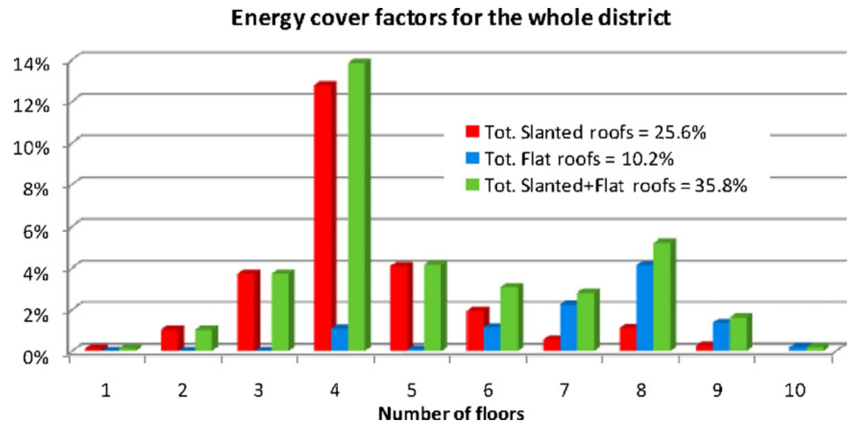


Fig. 7. Yearly energy cover factors for the whole district, versus the number of floors.

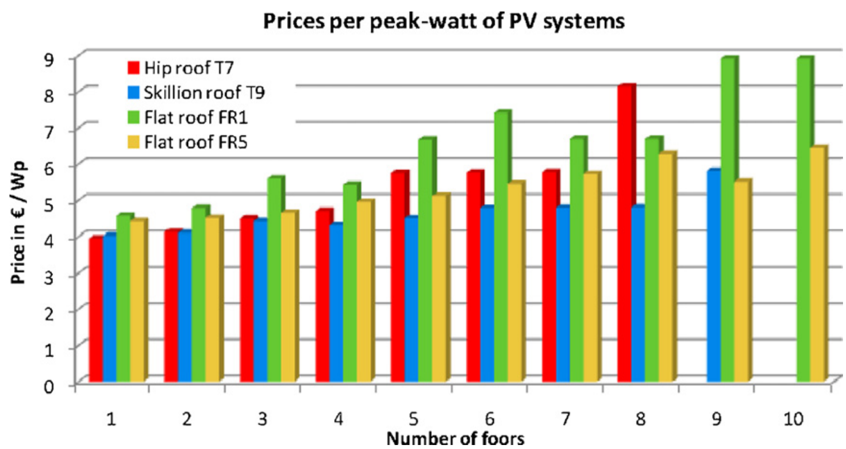


Fig. 8. Price per peak-watt of PV systems installed on slanted and flat roofs versus the number of floors.

For the gain in selling electricity the selling price of 0.102 €/kWh fixed by the Italian Authority was used. The net gain was calculated charging an income tax of 30.22% in selling the exported PV electricity. This tax was estimated on the basis of the average income of the inhabitants of Palermo.

The values of the FIT settled by the decree issued in 2010 by the Ministry for the Economic Development were assumed for the financial incentives; the values of the FIT are reported in Table 13. Only the FIT for the electricity sold to the Authority is paid in other countries while in Italy the producer receives FIT for the whole produced electrical energy and a payment for the part of the sold electricity. The FIT will remain constant for the next 20 years after the grid connection.

Costs were assumed from the market prices of components, considering the cost for labour and fitter's gain (Table 14).

The price per Wp at standard testing conditions (solar irradiance of 1000 W/m^2, module temperature of 25 °C, solar spectrum of mass air 1.5) of the cheapest and the most expensive PV systems, respectively, installed on slanted and flat roofs are shown in Fig. 8.

The price per peak-watt tends to increase with the height of buildings. Due to the non-linear dependence from the size of the PV field, the cost of a PV system installed on a building with eight or nine floors may double the cost of PV systems installed on buildings with two floors. The future costs and revenues of the PV technologies were determined as following:

- the decreasing of the efficiency of the PV panels every year, set to 1% of the nominal initial value;
- the maintenance and management costs, fixed at 2% of the investment cost every year;
- the replacement of 1% of the PV panels every year and of all inverters every 5 years;
- the yearly increasing of 5.2% in the price of electricity derived by the trend line calculated with the data issued by the AEEG [33] and shown in Fig. 9;
- the assurance costs, varying from 178.00 € to 297.00 € for PV systems with peak-power of 3 kWp and 15 kWp, respectively;
- the effect of inflation with a consumer price index of 2.1% [34], used to time-discount the costs during the time.

All above economic factors were considered to calculate the cash flows for 20 years, which is the time when FITs are provided in Italy. The weighted average cost of capital (WACC) was fixed at current value of 4.36% for all simulations regarding NPR and IRR.

Table 13
Feed-in tariff in 2011 for electricity generated by PV systems in Italy.

Rated power [kWp]	First 4-month period of 2011	
	PV systems installed on buildings [€/kWh]	PV systems not installed on buildings [€/kWh]
1–3	0.402	0.362
3–20	0.377	0.339
20–200	0.358	0.321
200–1000	0.355	0.314
1000–5000	0.351	0.313
>5000	0.333	0.297

Table 14
Prices of PV system components.

Component	Market price [€]	L&F [€]	Installed price [€]
PV panel 210 Wp	450.00	175.00	625.00
Roof-top mounting system (1 PV panel)	40.50	41.50	82.00
On-roof mounting system (1 PV panel)	12.50	34.50	47.00
Connectors for PV panel	8.00	2.00	10.00
4 mm^2 DC cabling (1 m)	0.95	0.85	1.80
6 mm^2 AC cabling (1 m)	1.50	1.00	2.50
Inverter MPPT 1.1 kW	700.00	245.00	945.00
Inverter MPPT 1.7 kW	910.00	315.00	1225.00
Inverter MPPT 2.5 kW	1195.00	415.00	1610.00
Inverter MPPT 3.0 kW	1300.00	450.00	1750.00
Inverter MPPT 3.6 kW	1390.00	480.00	1870.00
Inverter MPPT 5.0 kW	2220.00	765.00	2985.00
Inverter MPPT 7.0 kW	2465.00	850.00	3315.00
Main switchboard	458.00	240.00	698.00

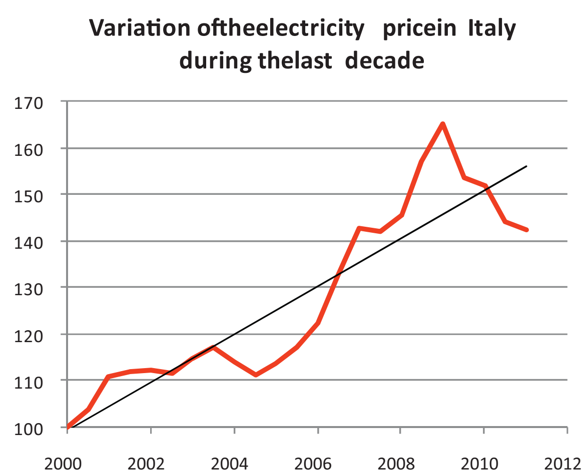


Fig. 9. Variation of the electricity price in Italy during the last decade.

4. Main results

The values of the FIT for the first 4-month period of 2011 were considered for the incentives. Only the electricity produced by PV systems economically convenient was considered to assess the energy cover factor. Fig. 10 shows the yearly energy cover factors filtered with the economic criterion; no shading effect due to surroundings was considered. The comparison with Fig. 7 shows the significant reduction of the energy cover factors related to the economic convenience of the PV installations; the energy cover factor of the district lowers from 35.8% to 24.1%, with a percentage decrement of 41%.

The PV systems placed on flat roofs cover only 3.4% of the district demand; they shifted from 28.5% of the global PV production to only 14% of the provided energy. About 50% of the global PV electricity is provided by the PV systems installed on the slanted roofs of buildings with four floors. Because the energy contribution of the building with a number of floors greater than five is only 3%, one may think that the placement of PV systems on those buildings is not worth to install.

As it is shown in Fig. 11, the reduction of the energy cover factors is even more significant if the effects of shading are considered.

Although the shadowing coefficient induces a reduction of the generated PV electricity that is directly proportional to its value, the effect on the cover factor is quite not proportional. With a reduction of 5% in the electricity provided by the PV systems, the cover factor of the district changes from 24.1% to 20.6%, which represents a reduction of 14.5%. When higher values of the shading coefficient are considered the reduction is even greater. In fact, a reduction of 10% of the electrical generation due to the shadowing causes a decrement of 37.8% in the energy cover factor of the district. With a shading reduction of 7.7% the cover factor reaches the 17.7%, which is close to the share of electrical energy from renewable sources in gross final consumption of energy that Italy should meet in 2020.

The method was also employed to assess the effect of the incentives in the next future. The average cost reduction of PV devices was strongly reduced in the last years and consequently the Italian Government recently decided to reduce financial subsidies. Starting from June 2011 the new values of the FIT have been significantly reduced, and from June 2012 they will lower to 60% of the values showed in Table 13.

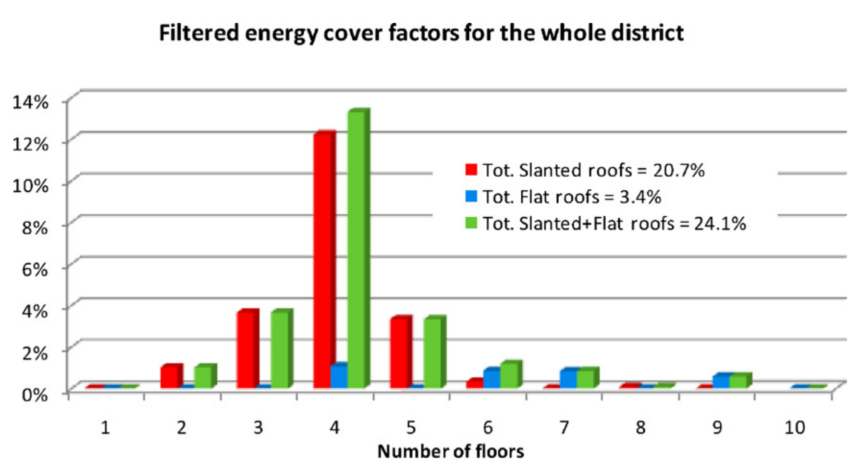


Fig. 10. Yearly energy cover factors for the whole district, filtered by the economic assessment, versus the number of floors.

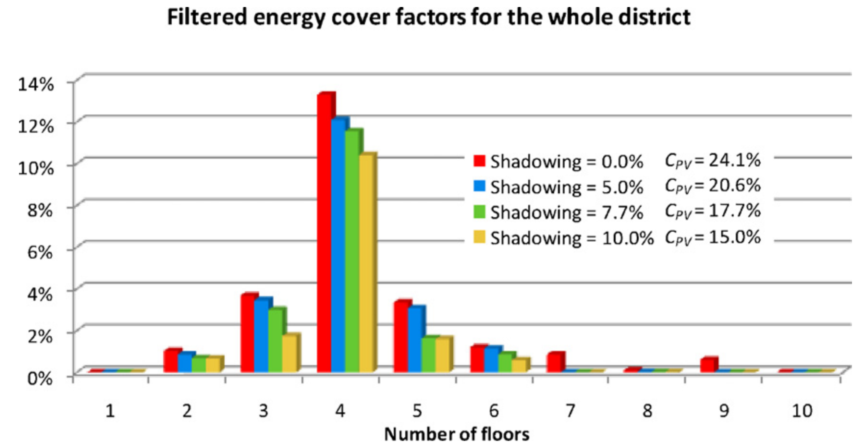


Fig. 11. Yearly energy cover factors for the whole district, due to the economic assessment, at various values of the shading coefficient versus the number of floors.

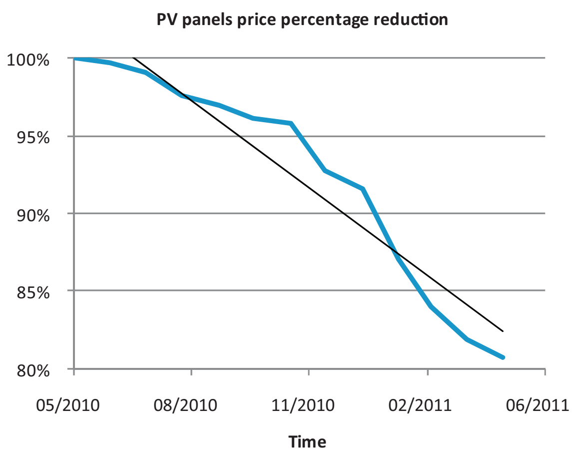


Fig. 12. Percentage reduction in the prices of the PV panels during last year.

Defining the optimal values of FIT could be pursued by means of the present methodology. To calculate the values of the FIT linked to the reduction in prices of the PV devices it is necessary to hypothesize the future trend of prices. On the basis of the past variations the economic analysts account that crystalline module prices will drop by more than 20% every year; a greater reduction is expected for polycrystalline modules. Figs. 12 and 13 show the percentage reduction in prices of the PV panels and inverters [35], which are the devices that mainly affect the cost of a PV system; the trend lines yield a yearly reduction of 20.4% and 14.5% for the PV panels and the inverters, respectively.

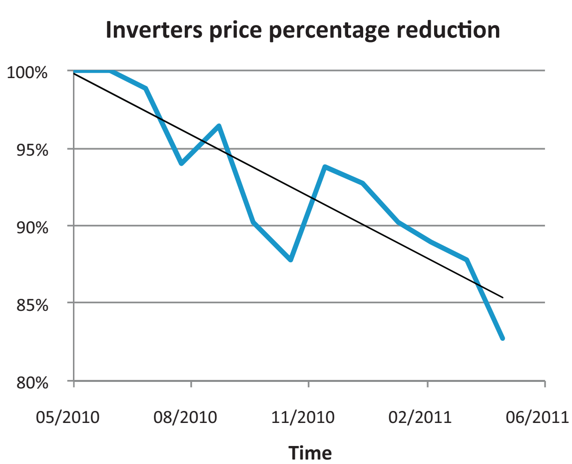


Fig. 13. Percentage reduction in the prices of the inverters during last year.

Table 15
Effect of FIT values on the energy cover factor.

Four-month periods	Yearly FIT reduction [%]	Energy cover factor of the district [%]		
		Slanted roofs	Flat roofs	Slanted + flat roofs
1st–2011	28	16.12	1.61	17.73
2nd–2011	28	16.12	1.34	17.46
3rd–2011	28	15.81	1.34	17.15
1st–2012	28	15.81	1.34	17.15
2nd–2012	28	15.73	1.34	17.07
3rd–2012	27	15.81	1.34	17.15

Assuming these constant trends, the reduction of the FIT that permits to keep a C_{PV} of 17% was evaluated. The results of the simulations performed assuming a shading coefficient of 7.7% and extended to the second half-year of 2012, are listed in Table 15.

With quite constant yearly FIT reduction of 28% it is possible to keep the energy cover factor close to the limit value of 17% for the next 2 years. This result disagrees with the trend of reduction proposed by the Italian Government for the same period of time. A comparison with the energy cover factors evaluated with the values of the FIT settled by the Italian Government is shown in Fig. 14.

The trend of reduction of the recently fixed Italian FIT value may produce in the short term a very irregular variation of the district

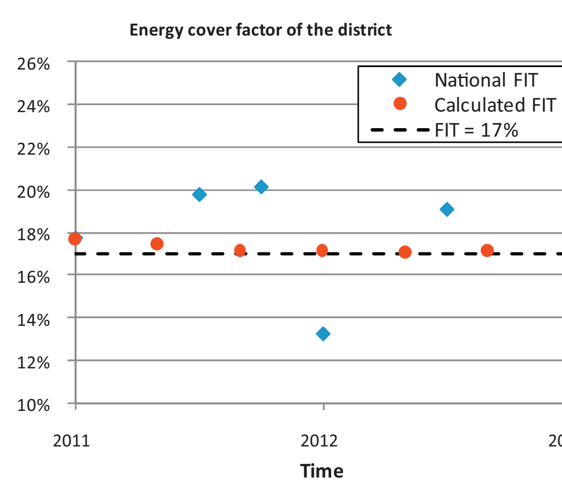


Fig. 14. Comparison between the energy cover factors evaluated with the Italy national FIT and the evaluated FIT.

energy cover factor; the fixed values for FIT figures out a swinging trend in price of PV devices by the end of 2012. The chosen values seem to be casual and they are not effective.

5. Conclusions

PV systems will play a paramount role to reach the 20-20-20 targets of EU in the Italian context. In fact, there are many advantages due to the employment of the PV systems in the urban context. PV technology is modular, which means that systems can be installed close to centres of demand and solar energy is the largest energy resource available in Earth.

Furthermore, peak production occurs during the day, typically coinciding, in hot regions, with peak electricity demand, often driven by air conditioning loads.

On the other hand, solar PV is a variable source of power and its integration into the grid could represent a challenge for system operators when it is used at a large scale.

The huge diffusion of the PV systems in Europe is due to the strong government support that has led to a boom in solar PV in recent years. At the same time, the price of PV installations decreased in the aftermath of the financial crisis. In July 2010, Italy passed legislation to cut tariffs by 20% on average.

Although these PV tariff cuts may appear at first sight to represent a weakening of government support for renewables, they are consistent with technology costs and market conditions, so a strong encourage the industry to became competitive and self reliant.

Due to the tariff cuts the importance of an accurate evaluation of PV investments will be of paramount importance to address investors towards more effective option and support decision makers in strategies of government support.

The paper shows a methodology for assessing energy and economic performances of PV systems in large urban context. Despite of the peculiar complexity of PV systems evaluations, due to a higher number of variables involved in the simulation, the proposed model is quite simple to use and it shows a good reliability in the estimation of the energy and economic benefits.

The method has a high transferability to different contexts and the procedure could be useful in determining the convenience of investments fitted to the local conditions.

The case study shows the significant reduction of the energy cover factors due to the lost of the economic convenience of investments. Shadings and incentives also play important roles in the reduction of the above factor.

Due to its simplicity, the methodology could be easily applied for energy planning purposes in urban contexts.

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